

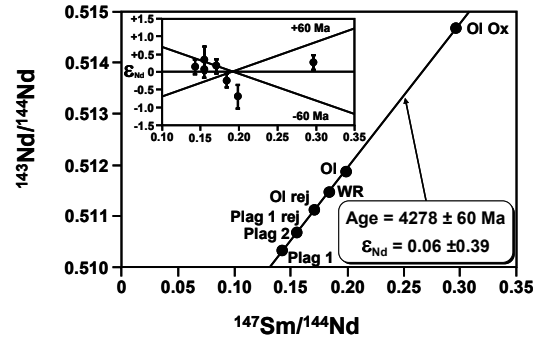
**Sm-Nd ISOTOPIC SYSTEMATICS OF TROCTOLITE 76335.** J. Edmunson<sup>1</sup>, L. E. Nyquist<sup>2</sup>, and L. E. Borg<sup>3</sup>,  
<sup>1</sup>University of New Mexico (MSC03 2050, 1 University of New Mexico, Albuquerque NM 87131-0001, Edmunson@unm.edu), <sup>2</sup>Johnson Space Center (Mail Code SR, NASA Johnson Space Center, Houston TX 77058),  
<sup>3</sup>Lawrence Livermore National Laboratory (7000 East Avenue, L-231, Livermore CA 94550).

**Introduction:** A study of the Sm-Nd isotopic systematics of lunar Mg-suite troctolite 76335 was undertaken to further establish the early chronology of lunar magmatism. Because the Rb-Sr isotopic systematics of similar sample 76535 [1] yielded an age of  $4570 \pm 70$  Ma [2,  $\lambda = 1.402 \times 10^{-11}$ ], 76335 was expected to yield an old age. In contrast, the Sm-Nd and K-Ar ages of 76535 by [3-7] indicate that the sample is approximately 4260 Ma old, one of the youngest ages obtained for a Mg-suite rock. This study establishes the age of 76335 and discusses the constraints placed on its petrogenesis by its Sm-Nd isotope systematics.

**Background:** Samples 76335 and 76535 are both composed of plagioclase and olivine, but have different modal mineralogies and extents of shock. The 76335 aliquot received for this study was composed of ~85% plagioclase, ~13% olivine, and ~2% oxides and impact melt. The sample is highly brecciated and often disintegrated into a fine powder during handling. Comparatively, 76535 has a modal mineralogy of 58% plagioclase, 37% olivine, 4% bronzite, and ~1% accessory minerals, and shows little evidence for shock metamorphism [8]. If shock disturbed the Sm-Nd isotopic systematics of 76335, it should be apparent when the Sm-Nd isotopic systematics of 76335 and similar sample 76535 are compared.

**Methods:** Approximately 2g of 76335 was crushed with a sapphire mortar and pestle and sieved. The 100-200 mesh size fraction was selected for magnetic separation, from which three mineral fractions were obtained for hand-picking. The mineral fractions were hand-picked to the highest possible purity at ~95x magnification. Samples were spiked with a mixed  $^{149}\text{Sm}$ - $^{150}\text{Nd}$  tracer. Chemical separation procedures and thermal ionization mass spectrometry were completed at the Lyndon B. Johnson Space Center.

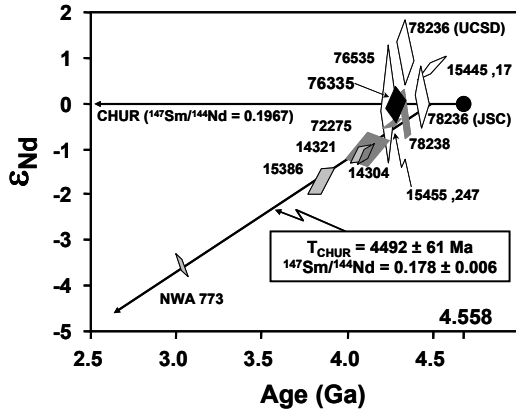
**Results:** The Sm-Nd isotopic systematics of 76335 yield an age of  $4278 \pm 60$  Ma (Fig. 1). This age is concordant with the relatively young ages determined for similar troctolite 76535 by [3-7]. The mineral isochron of 76335 indicates an  $\epsilon_{\text{Nd}}^{143}$  value of  $0.06 \pm 0.39$  relative to the chondritic uniform reservoir (CHUR) at the time of crystallization. The initial  $\epsilon_{\text{Nd}}^{143}$  value of 76335 is  $-0.76 \pm 0.39$  if the HED parent body composition of [9] is used to describe the bulk Nd isotopic composition of the Moon, as suggested by [10].



**Figure 1:** Sm-Nd isochron for 76335 indicating an age of  $4278 \pm 60$  Ma with an initial  $\epsilon_{\text{Nd}}^{143}$  value of  $0.06 \pm 0.39$  relative to CHUR. Normalized to  $^{146}\text{Nd}/^{144}\text{Nd} = 0.724134$ . Values calculated using Isoplot [11]. Inset shows the deviation of each point from the isochron in  $\epsilon_{\text{Nd}}^{143}$  units. Plag = plagioclase, rej = material rejected during the hand-picking process, WR = whole rock, Ol = olivine, Ox = oxide and impact melt-rich separate.

**Discussion:** The relatively young age and chondritic initial  $\epsilon_{\text{Nd}}^{143}$  value was not expected in the analysis of 76335. According to previous estimates [e.g., 12,13], KREEP-rich samples have source regions with a  $^{147}\text{Sm}/^{144}\text{Nd}$  ratio of  $0.178 \pm 0.006$ . This KREEP component is thought to have formed  $4492 \pm 61$  Ma ago (Fig. 2). However, the 76335 Mg-suite troctolite does not lie along the KREEP trend. There are a few reasons why this may occur.

(1) The Sm-Nd isotopic systematics of 76335 are disturbed. This scenario would seem likely, given the highly brecciated state of 76335. In fact, the Sm-Nd isotopic systematics of 76335 could be disturbed without sacrificing the linearity of the isotopic data [e.g., 14]. Experimental thermal disturbance of mare basalt 15555 showed that the Sm-Nd age of the sample decreased, and the initial  $\epsilon_{\text{Nd}}^{143}$  value increased, with increasing temperature. However, sample 76535, which shows little evidence of shock metamorphism [8], has nearly the same age and initial  $\epsilon_{\text{Nd}}^{143}$  value as 76335 (Fig. 2). Thus, it seems unlikely that the isotopic systematics of 76335 would be disturbed, unless the same disturbance occurred in the Sm-Nd isotopic systematics of 76535.



**Figure 2:** Time versus initial  $\epsilon_{Nd}^{143}$  value of KREEP-rich samples [12,13]. Black polygon = troctolite 76335, white polygons = samples not used in the linear regression for  $^{147}\text{Sm}/^{144}\text{Nd}$  ratio estimate of KREEP-rich sources, dark gray polygons = Mg-suite samples, light gray polygons = KREEP basalts and KREEP-rich olivine cumulate NWA 773.

(2) Sample 76335 is a product of mixing between a KREEP and LREE-depleted (positive  $\epsilon_{Nd}^{143}$  value) reservoir. It is possible that this sample originated as a melt in a KREEP and Mg-rich reservoir. The melt may then have risen as a diapir into the ferroan anorthosite (FAN) crust. The Sm-Nd isotopic systematics of FANs indicate that they have positive  $\epsilon_{Nd}^{143}$  values [e.g., 15]. The melt could then have assimilated a portion of the crust as it crystallized, influencing the Nd isotopic signature of the 76335 source. The difficulties in this scenario lie in the conclusions that Mg-suite samples would not have such high Mg#s if they simply assimilated crustal material during crystallization [16], and that FANs should represent LREE-enriched source regions [17] with negative  $\epsilon_{Nd}^{143}$  values relative to CHUR and therefore may not correctly represent the isotopic composition of the lunar crust.

An alternate mixing scenario could involve the mixing of reservoirs with Mg-rich, LREE-depleted cumulates and KREEP-rich, LREE-enriched material. From this single mixing scenario, there are two possible situations that can be described. The first situation involves a late differentiation age of the Moon [e.g.,  $4320^{+56}_{-40}$  Ma; 18,19]. In this case, a Mg-suite troctolite could have formed from reservoirs with different REE patterns, but the same  $^{143}\text{Nd}/^{144}\text{Nd}$  isotopic ratio (due to the lack of time required to grow observable

positive or negative  $\epsilon_{Nd}^{143}$  values). This seems unlikely given the ages and initial  $\epsilon_{Nd}^{143}$  values of the Mg-suite norites in Fig. 2, as well as the relatively old Hf-W and Rb-Sr ages for lunar differentiation [19,20]. The second situation is that the Mg-rich cumulates and KREEP reservoirs formed early, but were isolated for long periods of time, and the mixing of their positive and negative  $\epsilon_{Nd}^{143}$  values, respectively, yielded a chondritic value for 76335. In this case, the rock would have to crystallize close to the mixing age of the reservoirs in order to have a KREEP REE pattern and a chondritic  $\epsilon_{Nd}^{143}$  value.

(3) The Mg-suite troctolites are different isotopically than the Mg-suite norites. Although this scenario seems unlikely, due to the established geochemical relationships between norites and troctolites in layered intrusions such as the Stillwater Complex and the similar trace mineral assemblages in the lunar Mg-suite norites and troctolite 76535 [1], it cannot, with the isotopic data currently available, be ruled out. Further study of the Mg-suite is therefore required to establish an isotopic link between the norites and troctolites.

**Conclusions:** The Sm-Nd isotopic system of lunar Mg-suite troctolite 76335 indicates an age of  $4278 \pm 60$  Ma with an initial  $\epsilon_{Nd}^{143}$  value of  $0.06 \pm 0.39$ .

These values are consistent with the Sm-Nd isotopic systematics of similar sample 76535. Thus, it appears that a robust Sm-Nd age can be determined from a highly brecciated lunar sample. The Sm-Nd isotopic systematics of troctolites 76335 and 76535 appear to be different from those dominating the Mg-suite norites and KREEP basalts. Further analysis of the Mg-suite must be completed to reveal the isotopic relationships of these early lunar rocks.

**References:** [1] James O. (1980) *Proc. LPSCXI*, 365-393. [2] Papanastassiou D. A. and Wasserburg G. J. (1976) *Proc. LSCVII*, 2035-2054. [3] Lugmair et al. (1976) *Proc. LSCVII*, 2009-2033. [4] Hinthorne J. R. et al. (1975) *LSVI*, 373-375. [5] Husain L. and Schaeffer O. A. (1975) *GRL*, 2, 29-32. [6] Bogard D. D. et al. (1975) *EPSL*, 26, 69-80. [7] Huneke and Wasserburg (1975) *LSVI*, 417-419. [8] Gooley R. et al. (1974) *GCA*, 38, 1329-1339. [9] Nyquist L. et al. (2004) *Symp. Ant. Met.*, 28, 66-67. [10] Nyquist L. et al. (2006) *GCA*, 70, 5990-6015. [11] Ludwig K. (2001) *Isoplot v. 2.49*, *Berk. Geoc. Cent. Sp. Pub.* 1a. [12] Borg, L. E. et al. (2005) *LPSCXXXVI*, #1026. [13] Edmunson J. and Borg L. E. (2006) *Workshop on Early Planetary Differentiation*, #4034. [14] Nyquist L. E. et al. (1991) *LPSCXXII*, 985-988. [15] Borg, L. E. et al. (2006) *GCA*, 70, 2679-2691. [16] Hess P. C. (1994) *JGR*, 99, 19,083-19,093. [17] Korotev R. L. et al. (1980) *Proc. LPSCXI*, 395-429. [18] Nyquist L. E. et al. (1995) *GCA*, 59, 2817-2837. [19] Rankenburg K. et al. (2006) *LPS XXXVII*, Abstract #1348. [20] Kleine T. et al. (2005) *Science*, 310, 1671-1674. [21] Nyquist L. E. and Shih C. -Y. (1992) *GCA*, 56, 2213-2234.